MASS INSECT CONTROL PROGRAMS: FOUR CASE HISTORIES*

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PREFACE

Insect control is a vast subject. It encompasses many methods of approach meant to protect a wide diversity of human resources, including the lives and health of humans themselves. Upon the success or failure of insect control programs have rested the fate of armies, of great canals and populous lands. Yet, though man has registered many practical successes against particular insect menaces, we do not yet understand fully the underlying dynamics of insect populations (or for that matter, of other animals, including man himself), and until we do, perfect control will probably continue to elude us in many cases.

However, there exist practical measures that have been used successfully to control or eradicate many kinds of insects, even though

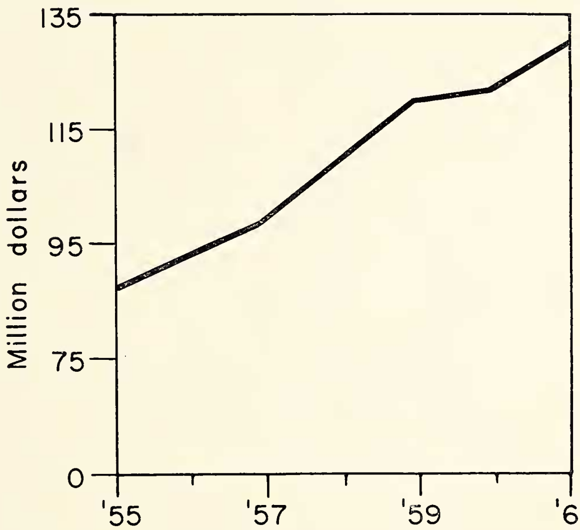

Figure 1. Insecticide sales by U. S. producers in recent years, projected through to the end of 1961. Domestic consumption of insecticides actually declined slightly during 1960 in the U. S., but exports more than made up this dip. From Chemical Week, July 22, 1961, by permission.

*This study and the report were sponsored and supported by the Conservation Foundation, New York.

we may not understand exactly how a particular measure takes its effect. In recent years, developments in practical insect control have come thick and fast, particularly in the field of pesticides. The development since World War II of chlorinated hydrocarbons, carbamate and organic phosphate insecticides, distributed by mass aerial spray techniques, has revolutionized control work and has raised insecticide production and aerial application to the status of big businesses. But, promising as it seemed in the immediate postwar years, simple mass aerial broadcasting of toxic materials has not always led to efficient control of the target pest. Furthermore, the extensive application of this relatively unselective technique inevitably caused damage to incidental targets — plants and animals or property valued by humans — and there even arose a threat to human health itself.[9, 20] As such damage and threat of damage became more obvious, protest against mass air-spraying increased in volume, and naturally the demand grew for research into alternative means of control.

It is my intention now to attempt to illuminate the current status and outlook of insect control methods in the United States by outlining four case histories of large-scale insect control programs. It is difficult to say how representative these case histories may be, considering the very diverse nature of insects and the damage each kind does. All four of the programs are large and expensive ones as such operations go, all have been considered to be eradication programs at one time or another, and all have been guided or conducted by agencies of the United States Department of Agriculture (hereinafter referred to as USDA).

Since these great programs affect or involve many people and many diverse vested interests, they are all to some extent controversial. Because controversy about them involves many contradictory findings and interpretations, it is often difficult to gain a true and unbiased conception of what is going on in a given instance. For this reason, I have tried to draw my information from as large and varied a group of sources as I could find (see Acknowledgements and References Cited). Let us now see if a resumé of four programs — Gypsy Moth, Fire Ant, Mediterranean Fruit Fly and Screwworm — will help us to appreciate the problems of mass insect control.

THE GYPSY MOTH

Introduction

The Gypsy Moth, *Porthetria dispar* (formerly *Lymantria dispar*), is a variable insect, a native of Eurasia, where it ranges from Portugal and North Africa to Japan. The insect was imported to the Boston area from France in 1869 by a misguided naturalist who believed that he could cross it with silkworms. Moths escaped from his breeding colony, but it was not until 1889 that the first severe outbreak defoliated fruit and shade trees in many towns of eastern Massachusetts. Control work was started by the state and apparently was successful, for populations were so low by 1899 that control operations were ended. The moth soon again built up extensive populations, and control work was resumed in 1905, but it had spread by this time to western Massachusetts and parts of Maine, New Hampshire and Rhode Island. In 1906, Congress voted aid to the infested states to help prevent the spread of the moth, but despite all efforts it continued to expand its range.

Biology and Nature of the Damage

The gypsy moth has a single generation per year. The winter is passed in the egg stage, and in New England the larvae hatch in mid-spring and feed through May and June, entering the quiescent pupal stage in early July. The larvae feed on a wide variety of broad-leaved trees and shrubs, especially oak, willow, poplar, birch, fruit trees and, in heavy infestations, even hemlock and pine. Dense populations may completely defoliate large areas of forest, weakening many trees and killing others outright.

The heavy-bodied female does not fly, but puts out a powerful scent to which the strong-flying male responds, even to extremely minute amounts carried on the air great distances, by flying upwind until contacting the source individuals and copulating with them.[18] The female deposits her eggs on tree trunks, fences, rocks and other solid objects. The young larvae spin silken threads on which they are easily spread by the wind before they start to feed.

According to Campbell[4] the strong fluctuations in abundance of the moth are density-reactive, a most critical factor in this reactivity being the larval behavior. At low densities, the caterpillars tend to descend to the leaf litter to rest during the daytime, and feed mainly at night out on the foliage. When density is intermediate, the larvae rest during the day under loose bark on the tree trunks, a habit that has been used to advantage in control work (bands of burlap placed around trunks of infested trees are removed daily and the caterpillars found beneath them are destroyed). At high densities, the larvae remain on the foliage day and night, and are subject to heavy losses due to disease, desiccation and attack by ichneumon-wasp parasites. Population "crashes" are correlated with previous high densities of larvae.

Control Problems

Early control efforts by the State of Massachusetts and the Federal Government included laborious and expensive methods such as hand-creosoting of egg masses, shelter-band and tanglefoot trapping on tree trunks, and various kinds of spray operations from the ground. For many years, control and quarantine programs appear to have confined the infestation to the area east of the "barrier" at the Berkshires and Green Mountains. Occasional extralimital infestations appearing in New Jersey, Ohio, Pennsylvania and Canada, particularly after egg masses were spread widely by the hurricane of 1938, apparently were eradicated before getting out of hand. Extensive introductions of predatory and parasitic insects from Europe and Japan were made beginning in 1905, and about ten such insects have taken hold in North America. Much of the subsequent history of the infestation was summarized in the report of the Gypsy Moth Eradication Meeting[11] held in Ithaca, New York, in September, 1957:

> "Following World War II, DDT was found to be a specific insecticide for the gypsy moth. At about the same time application of insecticide by plane became a practical undertaking. It was a new day for gypsy moth control. Heavy infestations within the area of general spread were suppressed or brought under control, and new infestations beyond the barrier were detected and held in check. Pennsylvania eradicated with reasonable effort and expenditure the gypsy moth on an area of 300,000 acres. Unfortunately more than 20 million acres were infested in this country before a practical control was discovered.
>
> For some unexplained reason, the gypsy moth infestations seemed to explode* in 1950 and there was rapid spread beyond the barrier zone. Following the outbreaks in 1953 and 1954, surveys revealed the new areas of infestation west of the barrier zone in New York, New Jersey and Pennsylvania, aggregating nearly 9 million acres. An isolated infestation found in the vicinity of Lansing, Michigan, was immediately scheduled for eradication. The occurrence of these infestations west and south of the barrier posed a serious threat of spread to the hardwood forests throughout the eastern and southern United States. The control and quarantine programs that had successfully held the moth in check for so long were no longer adequate. . . ."

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*The explosion might better be said to have fairly begun in 1951 or 1952; see Figure 2. Its inception so soon after mass air spraying of DDT began on an operational basis is a phenomenon which, curiously enough, seems to have attracted little attention. It was first pointed out to me by Prof. F. M. Carpenter of Harvard University. — W. L. B.

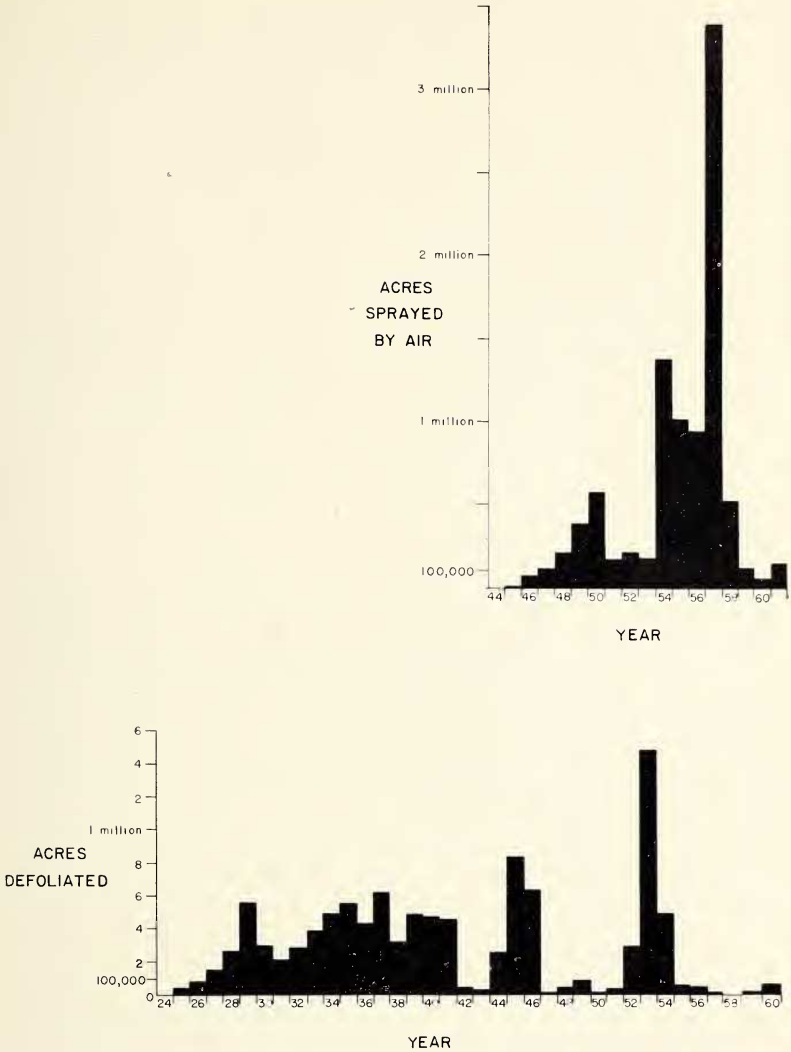

Figure 2. Graphs to show the ups and downs of the struggle against the gypsy moth in the U. S. Acreage showing substantial defoliation by gypsy moth larvae each year (below) is compared with acreage sprayed from the air (above) mostly with DDT at 1 lb per acre. Some suppression treatments used only 1/2 or 3/4 lb of DDT per acre, and sevin has partly replaced DDT in recent years. For details, see summaries by USDA in Appendix A, upon which these graphs are based.

In spite of the difficulties involved, Federal and some state authorities were still speaking in terms of "eradication" of the gypsy moth in 1956 and 1957, while other state and local people were by this time hesitant about backing an all-out eradication effort.

In 1957, after about three and one-half million acres had been sprayed (two and one-half millions of them in New York State), DDT residues were found on forage crops and in the milk of cows that had grazed on treated areas in New York State, as well as in eggs from poultry farms that had received spray.[16] DDT tolerances for milk are set at zero by the Federal Food and Drug Administration and by health authorities in New York among other states.

When the DDT residues were found persisting on forage crops and in the raw milk for periods up to a year, New York suspended eradication efforts ". . . so that," as the USDA's *Cooperative Plant Pest Control Programs* for 1958 put it, "the 1957 work could be fully evaluated and any required 'mopping up' could be done; however, during the eradication season tests were made of several alternate insecticides more suitable than DDT for use on pasture and forage crops."

Since 1958, New York has been doing a greatly reduced amount of spraying by air, using in part the new insecticide *sevin,* a carbamate having very low toxicity to mammals and birds, and one leaving no residue in the milk. Unfortunately, sevin is not as good against the gypsy moth as is DDT, it is highly toxic to honeybees, and it injures plants to some extent.

Aside from the dairy-linked residue problem, DDT has received rather good marks from most biologists checking the general ecological effects of mass spray at one pound to the acre. A few fish are sometimes killed, birds that catch insects on the wing depart, and certain aquatic insects suffer, but the known damage does seem tolerable. Long-term residual effects on soil organisms are, however, not well known.

The chief short-range danger of mass aerial DDT campaigns lies with the loose spray practices or accidents that result in duplication (or worse) of spray strips in a given area. Field insect control men often complain about the quality of pilots available for some spray programs, and numerous incidents have occurred to illustrate the point that some of the pilots are irresponsible or incompetent, or that they are poorly directed. For this and other reasons, it seems certain that operational mass spraying does not always give the same safe results as are found for the neatly-sprayed test strips of some of the studies, and landowners are often justified in complaining of double or triple doses of spray on their land. In view of these difficulties, DDT must be considered as only a marginally safe compound even at the 1 lb per acre dosage.

The issue of mass spraying has come to one court battle that attracted considerable attention. A group of plaintiffs led by Dr. Robert Cushman Murphy, the well-known ornithologist, sought injunctions against mass spraying of DDT for gypsy moth on or near their land, which was situated near New York City and mostly on Long Island. Most of the plaintiffs were organic gardeners and nature-lovers, and much of their testimony tended to be emotional in tone but rather insubstantial as to verifiable facts. The government defended itself with toxicologists and entomologists who presented a generally factual picture, and the case was decided against the plaintiffs by the Federal judge, although he warned the government to use more care in spray operations. The main effect of the case appears to have been to make the spray agencies hesitant about treating Long Island and many other farm areas. Also, by agreement with New York health authorities, a wide belt is left unsprayed around the large reservoirs of the metropolitan water supply. Such areas can of course provide refuges for the moth from which it is potentially able to recolonize adjacent treated areas.

Thus, for various reasons, the large key "border state" of New York has in fact been forced to abandon the "eradication" campaign, and the Plant Pest Control Division of the USDA now speaks instead of a "containment program" which would include chemical treatments within the infested area and along its periphery to back up the continued quarantines.

Infestations in Pennsylvania and Michigan, thought on several past occasions to have been eradicated or nearly so by DDT spray, still survive. Directly menaced are the hardwood forests of the Atlantic Slope, the Appalachians and the Mississippi Valley.

What Can Be Done About the Gypsy Moth?

I gather from conversations and correspondence with entomologists and foresters responsible for gypsy moth control at the state and local level that they generally share an uneasiness about the use of air-sprayed non-specific poisons such as DDT and sevin on forest and watershed areas. Most of them expressed the hope that some substitute control method eventually would be found. So far as we can see now, potential substitute methods lie in four different areas: predator-parasite manipulation, propagation of bacterial or viral diseases, baiting with attractants, and genetic disruption. In briefly discussing these topics, we should not overlook the possibility that there may exist entirely different modes of attacking the problem that have not yet occurred to anyone.

Predators and parasites. As already mentioned, a number of predaceous, parasitic and parasitoid insects, mainly beetles, flies and wasplike types, have been successfully colonized in the United States after being brought from Europe and Asia. Different ones attack every stage of the moth, from egg through adult, but few of them are strictly specific to the gypsy moth. The efficacy of the parasites is now open to question, since they have obviously not prevented serious outbreaks in areas where they are known to be established. Nevertheless, some natural enemies are known to be very effective at high densities of the host, and their value in the absence of possibly disturbing chemical control has not been thoroughly checked in recent years. Furthermore, it is likely that the established introductions represent only a fraction of the potentially useful arthropod enemies of the moth existing in Eurasia or elsewhere. In theory at least, there remains the possibility of keeping the moth at a tolerable population level by means of natural enemies, especially if used in conjunction with other biological control methods. Further research on natural enemies of the moth would certainly be desirable.

Disease propagation. The gypsy moth larva is susceptible to certain bacterial and viral diseases, among which *Bacillus thuringiensis* shows enough promise to have stimulated large-scale tests by Federal and state agencies. These tests, only partly completed, employ a "sticker" of tung oil or one of the improved English Lovol products to fasten the bacterial spores to the foliage. The suspension of spores in sticker can be sprayed from the air, and presumably is not harmful to plants or wildlife. So far, results have not been encouraging.

Attractants. The female gypsy moth, as already stated, can flutter along the ground or over low plants, but she cannot truly fly for any distance. The strong-flying males, like those of many moths, are strongly activated, even over long distances, by scent released by the female from the terminal segments or "tip" of her abdomen. Upon sensing even minute amounts of this scent, the male responds by flying upwind, in this way automatically approaching the scent-producing female, and ultimately coming near enough to mate with her. The scent obtained by extracting the female tips in benzol has been used for years as a lure in metal or paper traps to survey suspected areas in order to determine whether males, and therefore a likely infestation, are present. The female tips are obtained by the laborious and extremely expensive rearing of thousands of hand-collected female pupae, many of them imported from Europe and North Africa. Costs have ranged up to a half dollar per tip in poor collecting years.

In 1960, after producing several moderately effective synthetic lures, M. Jacobson and his co-workers of the Entomology Research Division, Agricultural Research Service, USDA, succeeded in isolating the principal sex attractant from some half a million female gypsy moth tips collected in Connecticut and Spain. The substance was prepared synthetically and found to be an ester alcohol with 16 carbon atoms in its main chain. In the course of preparing the natural lure, a closely related substance (with 18 carbon atoms in its main chain) was also found to act as a strong gypsy moth lure.[17] This preparation, named *gyplure,* has the advantage that it can be synthesized cheaply and in quantity from ricinoleic acid, a common component of castor oil. Tested in field traps, quantities of this substance as small as one microgram proved equal in luring power to traps baited with the natural lure. In 1961, as this is written, field trials are being carried out to test the efficacy of gyplure-toxicant combination baits in reducing moth populations. Included in this program are "confusion" tests with saturated levels of gyplure in granular and spray formulations. Initial technical difficulties have been met, but it is hoped that these can be cleared up during the 1962 season. It will be appreciated that many hopes ride on these crucial trials.

Genetic methods. The success of the screwworm eradication program (see below) has raised the possibility that the release of sterilized males might be used to control or eradicate gypsy moth populations. This possibility remains to be explored by further studies of the moths' mating behavior and physiology and the practicability of rearing, sterilization and release procedures. Sterile male release might be made much more effective after reduction of the population by bait attractants or other means.

Other theoretical possibilities for control rest in the fact, discovered years ago by R. B. Goldschmidt, that certain different native Old World populations of *P. dispar* differ in their sex-determining mechanisms in such a way that crosses made between them produce intersexes. It can be argued that the overall fitness of a population might be cut by introducing north Japanese strains into the American populations, which originated in France. The possibility is worth investigation despite some theoretical difficulties.

THE IMPORTED FIRE ANT

Introduction

The fire ants belong to seven or eight New World species in the *geminata* group of genus *Solenopsis.* The group as a whole has a tropical warm temperate distribution throughout the Americas, from southeastern and southwestern U. S. to central Argentina and Chile. The species are quite closely related and are similar in their habits. All form populous nests, at maturity containing 25,000 to more than 200,000 active and aggressive adult workers. The workers in a mature nest vary considerably in size from large soldiers down to much more numerous minor workers only 2-3 mm long, and usually only a single functional queen is present. Nest foundation follows the pattern typical for ants, in which virgin winged females mate with males during a nuptial flight, then quickly shed their wings and, as young queens, burrow into the soil and begin the rearing of the first brood in a small chamber. Later, as the nest grows, it usually comes to be capped by an earthen mound sometimes two feet or more high and often two or three feet in diameter.

Up to the First World War, only three of the fire ant species were known to occur in the U. S., of which two, *Solenopsis xyloni* and *S. geminata* (native fire ant) were found in the southeastern states. It seems possible that the "native" fire ant is itself a post-Columbian introduction, and it has been spread widely over the tropics of both hemispheres by human commerce. In past years, *S. geminata* had gathered to itself much the same reputation as a nuisance now generally assigned to the late-coming imported fire ant (*S. saevissima*) that is the subject of this discussion. The imported fire ant arrived at Mobile, Alabama in produce or ballast at or a few years after the end of the First World War. At first the ant (then represented solely, so it seems, by a blackish phase with a dull orange band at the base of its gaster — the so-called "variety *richteri,*" common in Argentina and Uruguay) spread only very slowly in Mobile and its environs. At some time around the beginning of the 1930's, a smaller, light reddish form of *saevissima* appeared in the Mobile area. This phase corresponds to populations of the species common in southern Brazil and Paraguay, and it seems most likely that its appearance marks a second introduction of *saevissima* into the Mobile Bay port area.

Coincident with the advent of the red phase, the entire *saevissima* salient in southern Alabama entered upon a period of rapid expansion that carried the main infestation across state lines by 1940. The expansion apparently has not yet reached its full extent, although infestations are or have been known to occur in ten states ranging from Texas and Arkansas to North Carolina and Florida. Expansion occurs in two main ways — by steady widening of the main infested areas due to short-range aerial spread of winged females, and through colonization ahead of the main infested area by queens and colony fragments transported by vehicular traffic. Nursery stock used to be a prime source of new infestations, but since nursery treatments and quarantine regulations have come into effect, fertilized females accidently carried in automobiles are probably responsible for most colonization.

Wherever the red phase has expanded to overcome the dark phase, the two extreme forms have interbred to produce a series of intermediates, and in most cases the red form soon comes to predominate by a process of genetic swamping coupled with its greater success in warfare between nests. In fact, it may not be too extravagant a speculation to conclude that it was the injection of the red-form genes into the existing dark population that sparked the spectacular spread of the species in the last three decades. At present, the North American population consists mainly of light reddish ants, the dark phase surviving mainly in peripheral situations and cool swamplands.

Wherever it spreads, *S. saevissima* tends to replace the populations of *S. xyloni* and *S. geminata* in its path, though this is less true of the dark-colored *geminata* occupying woodlands in Florida and perhaps elsewhere[26]; *saevissima* in the U.S. generally avoids shaded situations. The imported fire ant is able to build up remarkably dense populations. I have seen pastures in eastern Mississippi in which it was literally possible to walk for a considerable distance by stepping from mound to mound without touching a foot to the ground between. Such situations are exceptional, and usually mark the entry of the species into a new area, or else follow control measures that have knocked out a stable population of old, large nests. When the old nests are eliminated, large numbers (up to 185 per acre) of smaller new ones take their places, but as they grow, nests are gradually eliminated until the density is again relatively low (10-50 nests per acre usually).

Studies made to date have not been critical enough to detect possible widespread population fluctuations in untreated areas, but about a century ago, Bates noted a radical change in a native population of *S. saevissima* in the Amazon Basin.

A small number of parasites of this ant are known in its native habitat, including several known or suspected inquilinous species of ants and a phorid fly, but no real study has ever been made of this phase of the ant's biology. These parasites have been lightly dismissed as a control possibility by previous writers, but it seems to me that the whole subject of parasitism should be looked into. Parasites might do much better in the U. S. than in their native range, and even a minor reduction in fire ant populations might reduce it appreciably as a nuisance in some areas.

Nature and Extent of Damage

The kind and extent of the damage done by fire ants has been the subject of much dispute. Generally, control agencies, and especially the USDA-affiliated ones, have emphasized the deleterious effects produced by the ant, while some zealous anti-insecticide writers have written it off as doing negligible harm. Both groups admit that the ant mounds do interfere with the harvesting of forage crops. Harvesting machinery is often damaged by striking the hard mounds, and field hands are stung by the ants — in some cases so badly that they refuse to work infested fields. Occasionally, land values have fallen somewhat in badly infested areas. The health threat must also be considered in cities and towns, where the ants may infest lawns and gardens and even sometimes enter houses. Small children and unusually sensitive adults have occasionally suffered grave illness, or in two or three cases may even have died as a result of fire ant stings. Numerous stings result in a rash-like group of pustules that can be very annoying for several days or more. Still, the fire ant as a health menace must be ranked far below ordinary bees and wasps, which are responsible for many times the deaths that fire ants cause during a given period of years, in the same states. It is difficult to see how the ant can be classed as a serious public health problem despite scare stories in the press, television and in a USDA-sponsored film. Professor F. S. Arant, head of the entomological contingent at Auburn University, current president of the Entomological Society of America, and a top authority on the fire ant, agreeing with Dr. J. L. George[10] and other state entomologists in the Southeast, calls the fire ant a "major nuisance," but deprecates its role as a crop pest. Studies made at Auburn[14] and elewhere in the South generally have borne out this evaluation. It is interesting to note that the studies[6, 27] that have found more or less serious damage done to crop plants were made before 1953. These studies were mainly concentrated in south-central Alabama, near the Mobile Bay center of fire ant spread, and were based on personal investigation as well as uninvestigated farmer reports. That some crop damage was done in this area in the late 'forties and early 'fifties is incontestable, but even then, the damage does not seem to have been insupportable. That more recent studies have failed to find serious crop damage is probably to be laid to a gradual change in the habits of the ants or their population density, or both. Whatever is the case, it does seem that the damage currently being done by the imported fire ant in the untreated sections infested in this country is less than would seem to justify the massive campaign that has been mounted against it. Agencies in all but two infested states do not even grant the fire ant a place in their lists of the more important plant pests. The USDA cites farmer support for the program, and this support certainly exists at least in some sections. But the enthusiasm of farmers for the spray programs is too often based merely on a vague feeling that insecticides in general are a good thing. When, as in large areas covered by the present program, the farmers individually get the spray free, they tend to overlook possible bad effects it may bring with the benefits. In any case, the satisfaction of farmers is certainly no substitute for a careful and extensive professional check of current fire ant damage. No such check has been made by the USDA, or at least none has been reported upon since 1952.

Control Operations

Control efforts directed against the imported fire ant were first initiated on a small scale by the State of Mississippi in 1948, without notable success. A survey of the infested area was begun by the USDA in the fall of 1948, and, together with limited investigation of the biology of the ant and control measures against it,[6] ran until research funds were stopped in 1953. This investigation did not deal with aerial control measures, and little attention was paid to wildlife damage. It is important to note that from 1953 until 1958, after the USDA had started its mass spray program, it spent no money for fire ant research.[22] Meanwhile, several independent agencies had done part-time research on various aspects of fire ant biology and control, including medical studies of the effects of the venom on humans at Tulane University, biological and control studies at Auburn and Mississippi State Universities, and behavioral and other investigations by Dr. E. O. Wilson and others (including the present author) at Harvard University and in the field. The Fish and Wildlife Service, although greatly hampered by lack of research funds for this purpose, was giving some attention to the prospect of mass broadcasting of insecticides as it could be expected to affect wildlife.

Against this patchy research background, in March, 1957, the USDA noted that it had requested the approval of Congress for control of the fire ant, and Congress forthwith passed a special "Federal Plant Pest Act," authorizing the USDA to take measures against the ant. For the 12 months beginning July, 1957, 2.4 million dollars was appropriated, to be matched by funds from state agencies, local sources and/or individual farmers. (In practice, actual matching appears to have been spotty at best, and the government has waived farmer contributions in Georgia and parts of Florida since early in the program.)

On April 18, 1957, after a brief correspondence with officers in the Entomology Research Division of the Agricultural Research Service, USDA, I received a letter from Dr. A. W. Lindquist, head of one of the sections in the Division, which started in part as follows:[22]

"The idea of airplane spraying and dusting for control probably stems from the fact that extensive areas are infested. This method of application would of course be fine if it were effective. However, we would want to see considerable research conducted to determine if it would be effective and, if so, to determine what insecticides and special precautions would be necessary for maximum results. As far as we know, no research along these lines has been conducted."

This answer may be compared with that received from Dr. M. R. Clarkson,[23] Acting Administator of the Agricultural Research Service, dated January 3, 1958, stating in part:

"In planning field operations, all available results of applicable research and practical experience are taken into account. Close liaison has been established with the Fish and Wildlife Service of the Department of the Interior and the states involved. Competent wildlife observers have been assigned to the work and experience to date indicates that a successful program can be carried out without serious consequence to wildlife resources. . . . Both the Agricultural Research Service and State Experiment Stations have *expanded* their research program in a *continuing* effort to improve operational procedures." (Italics mine — W.L.B.)

In May, 1957, as a matter of record, Dr. Ross Leffler of the Department of the Interior had written to Representative H. C. Bonner, Chairman of the House Committee considering the bill, as follows in part:

"Sufficient basic research has not been accomplished to predict losses or to properly advise operating agencies on the means of obtaining effective control and at the same time avoiding unnecessary fish and wildlife mortality."

With astonishing swiftness, and over the mounting protests of conservation and other groups alarmed at the prospect of another airborne "spray" program, the first insecticides were laid down in November, 1957. The rate of application was two pounds of dieldrin or heptachlor per acre, the insecticides being incorporated in granules of an inert material to cut down wind drift and lessen loss by foliage interception. It had been established that this formulation would be spread in the upper soil layers when rain dissolved the granules, and that its effect would last at least three years.[1] Dieldrin was used at three pounds per acre wherever another pest, the white fringe beetle, occurred as well as the ant, thus treating for both pests at once. Where the ant occurred alone, heptachlor was usually the choice. Dieldrin and heptachlor are extremely toxic substances — about 4-15 times as toxic to wildlife as is DDT.[8] Many wildlife experts and conservationists, as well as entomologists both basic and economic, felt a sense of foreboding at the start of a program that would deposit poisons with 8-30 times the killing power of the common forest dosage of DDT (one pound per acre in gypsy moth control).

The spray campaign got off to such a fast start that both state and Federal agencies were caught without being able properly to organize programs that year for assessing the effects of the poisons on wildlife, so that results of such programs were delayed until after large amounts of toxicants had already been laid down.

Now that some of these results are finally available, we can see that they were acutely needed before the program was ever begun. The misgivings of the wildlife people seem to have been justified on the whole, since the kill of wildlife in sample treated areas appears to have been high in most of those that were adequately checked.[5, 8, 10, 12, 21] The USDA disputes many of the claims of damage, but their own statements often tend to be vague and general. It does seem to be true that quail and perhaps other wildlife species will make a good comeback on treated land after two or three years, *provided that untreated areas are available nearby* to furnish replenishment stocks once the treated land begins to recover. Still, most of the information on wildlife repopulation comes from the accounts of hunters and other sources not subject to proper checking, and we still have little in the way of published studies by competent authorities on ecological recovery of treated lands.

Wash-off into streams and inlets has led to heavy losses among fish, crayfish and aquatic insects. Dieldrin at only one pound per acre sprayed on a salt marsh at Vero Beach, Florida, killed all the fish (including young tarpon) and Crustacea in the marsh and adjacent waters, and the effect lasting for weeks.[12] This particular test, meant to control sandfly populations, applied only half of the dosage of dieldrin originally used for fire ant control, and one-third the dosage actually used on white fringe beetle together with fire ant.

Although the USDA claims that the evidence is inconclusive in some cases, there does exist contrary information[7, 10] indicating that stock losses from fire ant poisons may sometimes be significant. Various newspaper accounts, while sensational in tone and possibly exaggerated, add further to the impression that damage to cattle, horses, poultry and household pets may on several occasions have been locally serious. Even a few livestock deaths, if added to the time and effort spent by farmers in carrying out awkward measures to protect their animals from spray measures, must more than balance out any cumulative loss that fire ants may have inflicted directly on farm stock since the infestation began.

In 1959, the formulation was changed to a dosage of 1.25 lb of dieldrin or heptachlor per acre, and more recently an alternative dosage of a quarter pound per acre has been most widely used. This latter dosage, used twice at three- to six-month intervals, was developed because of the growing concern about wildlife and the residue problem. At this rate of application, wildlife apparently suffers much less seriously, but the fire ant is also much safer than under the old rate of two pounds per acre, and can probably come back in many places a year or two after the "light treatment" has been applied, according to the data of Blake, Eden and Hays[1] for similar dosages. Wildlife officials claim to have heard from Plant Pest Control officers that there still exist stockpiles of the formulation yielding two pounds of actual heptachlor or dieldrin per acre, and that this product was still being used for treating junkyards as of March, 1961, but Dr. E. D. Burgess of Plant Pest Control denies that this is so.

A serious blow was dealt the program in late 1958, when treatments were only one year old; Senator Sparkman and Congressman Boykin of Alabama asked that the fire ant campaign be suspended until its benefits and dangers could be evaluated properly. Then, in the beginning of 1960, the Food and Drug Administration of the Department of Health, Education and Welfare lowered the tolerance for heptachlor residues on harvested crops to zero, following the discovery that heptachlor was transformed by weathering into a persistent and highly toxic derivative, heptachlor epoxide, residues of which turn up in meat and milk when fed to stock. Some state entomologists now definitely advise farmers against the use of heptachlor on pasture or forage.

At just about the time that the residue question arose, the Alabama State Legislature refused to appropriate state funds for participation in the program after hearing evidence from state entomologists and some farmers that the fire ant is a nuisance rather than a direct source of serious harm to crops or farm animals. (Alabama voted some participation funds again in 1961.) Alabama was followed out of the program by Florida in the spring of 1960. According to a U. P. release on March 26 of that year, Florida Plant Commissioner W. G. Cowperthwaite announced, "Efforts to stamp out the fire ant permanently in Florida have failed." He said that "the all-out attack on the pest is being abandoned. In its place a control program centered on badly contaminated areas will be set up. We thought at one time we could eradicate the fire ant, but it is impossible."

It seems likely that Mr. Cowperthwaite's words accurately express the situation for the South insofar as the present means of control are employed. The original plan set forth in 1957 called for eradication of the ant on the North American continent, by rolling back the infestation from its borders, applying eradication measures to more central foci in the main infestation, and instituting an effective program of treatment of especially dangerous sources of spread, such as nurseries. Nearly four years and perhaps 15 million dollars after that plan was announced, the fire ant is still turning up in new counties, and is being rediscovered in counties thought to have been freed of the pest in Arkansas, Louisiana, Florida and North Carolina. Undoubtedly, as the task of surveying for an elusive quarry continues, more reinfestations will turn up, and further "spot control" will be needed. Some two and one-half million acres, a little less than one-tenth of the total acreage known to have been infested, have now been treated with one or more of the formulations discussed above (July, 1961).

What Can Be Done About The Fire Ant?

Even before the aerial spray program began, independent research workers had brought to the attention of the USDA authorities the potentialities for fire ant control residing in the use of baits, both poisoned and otherwise. New approaches to the use of baits were being explored at the time at Harvard, and a good start was being made at Auburn University; the two investigations have since brought forth different but very promising results.

Difficulties in using most poison baits against ants include the development of social "bait shyness," a term that describes the fact that ant colonies will often "learn" to avoid baits that have been taken by, and presumably have killed, some of their foraging workers. It is not known how bait shyness arises in the colony. Hays and Arant[13] have developed a new peanut butter bait in which very low concentrations of a new, extremely slow-acting poison called Kepone® are mixed and squeezed into short lengths of paper soda straws. These baits have proven to be extremely effective against the fire ant in test plots in Alabama, probably because the Kepone takes five to seven days to kill, and thus puts off bait shyness until the entire colony has fed upon the poison. The USDA has also recently completed some bait tests. The effect of these formulations upon wildlife has not yet been fully tested, and there may be a hitch in this direction.

Perhaps even more promising is work done over the last few years by E. O. Wilson at Harvard[25] and M. S. Blum and his associates at Louisiana State University[2] with the so-called "trail substance" of the fire ant. This material, found in one of the sting glands of the ant, is used by the ants to mark trails leading back to the nest from food sources or other attractive objects. This liquid is released through the sting, which is used like a pen to draw a trail on the ground. The odor of the trail substance induces stereotyped foraging behavior, and also serves as the marker along which the ants run. Apparently, each species of fire ant has its own distinctive trail substance. At the present writing, the chemical composition of the trail substance is not known, but like other natural products, it will eventually be worked out, and synthesis of its components and related compounds should be possible. The trail substance has the advantage that it is a necessary part of the ants' communication system, and it is extremely potent. Presumably, it could be used to lead the ants to poison baits, or, more hypothetically, it might be used as a "confusion lure," broadcast in high concentrations, leading the ants to forage fruitlessly in all directions.

THE MEDITERRANEAN FRUIT FLY

Introduction

The Mediterranean fruit fly (or "medfly," *Ceratitis capitata*) and other fruit flies of greatest importance belong to a family (Trypetidae) of the two-winged or true flies (Diptera). They are not to be confused with the fruit flies of genetics, which are primarily yeast-feeders of the genus *Drosophila,* belonging to another family of the same order.

Biology and Nature of Damage Done

The adult true fruit flies vary from much smaller than a house-fly to somewhat larger, and they usually have their wings "pictured" with dark markings. In the usual case, the fruit fly female, after mating, will puncture unripe fruit and deposit one or more eggs in the incision. The larvae are whitish or yellowish maggots that feed in the fruit on the branch, and then either drop to the ground, or leave the fruit after it drops, and pupate in the soil. Infested fruit is, of course, rendered unfit for human consumption. Host fruits infested are citrus, peach, mango and about 200 other fruits and vegetables. Although some true fruit fly species are found in temperate regions, most, including the medfly, are at home in tropical or subtropical climates.

In a climate like that of Florida, the medfly can produce about 10-12 generations per year, since the life cycle is completed in slightly under one month in warm weather. The medfly is a native of Africa, but it has spread to most of the world's citrus-producing areas in infested fruits carried by human commerce; the United States is one of the few such countries that have managed to exclude it. Since 1912, U. S. Plant Quarantine has intercepted the medfly over 1600 times at various ports of entry in this country, and it became established here twice, in 1929 and again in 1956, both times in Florida. On both occasions, vigorous efforts by combined Federal and state forces eradicated the fly before it could become established outside of Florida, and at present writing, the pest has no known breeding population in the continental United States.

The 1929 Campaign

On April 6, 1929, larvae were discovered in grapefruit at Orlando, Florida, and by April 10, adult flies had been found and positively identified as Mediterranean fruit fly. The Florida State Plant Board and the USDA sprang into action immediately, shifting inspectors to the area, and by May 1, 1929, a quarantine was invoked in connection with a program aimed at prevention of spread of the pest and its eventual eradication. Quarantine stations were set up on railways, roads and ports on coastal waters and inland waterways. The quarantine of automobiles moving north and south from the infested area proved difficult, but was strictly enforced — when necessary, with the help of the National Guard. Between 410,000 and 625,000 vehicles were examined each month, of which 6,900 to 13,100 were found carrying contraband material, including fruits, vegetables, soil, nursery stock, compost, etc.

Within the affected area, all actual infestations discovered and the area surrounding each one for one mile were designated as "infested zones," while a "protective zone" extended for another nine miles beyond every infested zone. Within the infested zones all known fruits and vegetables were destroyed in order to deprive the flies of breeding opportunities. Removal of host fruit was continued in the infested zones, and no vegetables were planted there. Packing houses were supervised in order to prevent shipping leaks through this channel and to enforce sanitary measures against possibly infested fruit lying around their premises. In both infested and protective zones, the foliage was sprayed with a bait preparation containing brown sugar and molasses plus a poison — lead arsenate or copper carbonate.

The extent of the effort may be judged from these figures: the treatment extended onto 1,002 properties in 20 counties with about 10,000,000 acres of land (containing nearly three-fourths of all the bearing citrus land in Florida), including 120,000 acres of citrus and 160,000 of non-citrus crops. About 609,000 boxes of fruit were destroyed in this area, and 25,000 outside it. Fifty thousand bushels of host vegetables were destroyed, and about 300,000 pounds of lead arsenate were used in the bait spray. Infested shipments were found in ten localities in seven states outside Florida, owing to the fact that three-fourths of the citrus crop had been marketed by the time the fly was discovered.

It was found that kerosene and certain fermenting materials were attractive to adult male flies, and glass traps containing these were used to check on the presence of the pest.

By July, 1930, the medfly could no longer be trapped in the continental United States. Its elimination took an expenditure of about seven and one-half million dollars and the employment of a peak work force of some 6,000 men. Reimbursement of those who sustained losses through confiscation of fruit or other control measures cost another seven million dollars. The "scorched earth" policy plus effective quarantine and the crude bait spray had paid off; the medfly had been eradicated for the time being on this continent.

The 1956 Campaign

The second medfly infestation began when infested grapefruit was found at Miami Shores in April of 1956. By June of that year, infestations were found in 19 Florida counties. Again, Federal and state forces were marshalled with admirable alacrity, but this time, after a brief initial period of fruit-stripping in some of the southeastern Florida counties, a new strategy was employed. In large part, this plan was devised by L. F. Steiner, USDA fruit fly expert, who had been working out control and detection methods for various pest fly species in Hawaii. Fruit-stripping was abandoned, and quarantine zones of one mile were established around each known infestation. All fruit or produce moving out of these areas had to be fumigated or processed immediately. New improved fumigation methods employing methyl bromide and ethylene dibromide were found quite satisfactory for most fruit, and could be applied at a rate of only five cents a box. Some loopholes were exposed. For instance, mangoes, which do not stand up well to fumigation, were sent unfumigated to Chicago, but were found to have been transshipped to Louisiana, a state vulnerable to the fly because of its mild winters.

Although over four and one-half million automobiles were examined at roadblocks, the spread of the fly mainly followed the highways, indicating that contraband fruit or adult female flies were moving by car. Other minor routes of dispersal occurred through Indian reservations, where mangoes were peddled after being transported by canoe and otherwise away from the roads, and through the traffic of guava pickers, who are independent and have their own pickup stations.

Direct control methods employed a spray containing a bait of protein hydrolysate ("sauce base" of the food industry) plus a poison component, the organic phosphorus compound, wettable malathion, mixed in just enough water to make up a spray that could be applied by air. This bait attracted flies from distances of over 200 yards away, instead of the few inches or feet over which the 1929 sweetened bait had proved effective. The new bait lured and killed almost all flies within 100 feet a few hours after their emergence, so that swaths missed by the planes did not matter so long as they were not excessively wide. By proper timing of sprays at seven to ten days apart, the flies were prevented from ripening to sexual maturity after eclosing from the pupal stage. Since the maggots were able to survive (in grapefruit and oranges left on the tree) for up to 20 days after reaching the final larval stage, the spray was continued for one full generation (50-90 days) after the last fly find.

Detection methods depended primarily upon substances that would lure male flies. Angelica seed oil in plastic traps with poison proved to be a highly effective attractant for males, but the different lots of the oil that were tried were found to be very uneven in their effectiveness. Furthermore, this commodity was rare and expensive — $100 or more per pound. By early 1957, some 800 pounds of the oil (the entire world production of ten years) had been used for fly baiting, virtually exhausting the world supply. The last angelica seed oil was offered on the world market at $500 a pound. Fortunately, at just about this time the chemists came through with an effective and relatively inexpensive substitute that they called siglure, containing certain simple esters of cyclohexane carboxylic acid. It was learned that the fruit flies tend to disperse from areas after fruit production has ceased, and this was a good reason for leaving fruit on the trees in infested areas. Fallen fruit was destroyed wherever possible.

An auxiliary control used in heavily infested zones was the application of a formulation at the rate of five pounds of dieldrin per acre to the soil under infested trees. This was aimed at pupating larvae and adults leaving the pupal stage.

The program progressed steadily. Infestations were found in a total of 28 counties, most of them south of the 1929 zone. While the 1929 infestation had affected mainly the major commercial citrus groves of central Florida, the 1956 invasion was centered more in the ornamental and dooryard plantings of residential areas in the southern part of the state. This required the use of more of the safer twin- and four-engined planes in the low altitude bait-application flights.

One year after the first discovery of 1956, nine-tenths of the total acreage had been treated, and only about 12,000 acres of new infestations remained to be discovered. One by one, during late 1956 and early 1957, counties were released from the aerial spraying routine after no more flies could be found in them, and in November, 1957, the last known infestation was eliminated from an island off the coast in Manatee County. The cost of the eradication program, paid jointly by the state and Federal governments, was about $11 million, but only small quantities of fruit had had to be stripped from the trees and destroyed.

Eight hundred thousand acres were sprayed one or more times — some of them up to a dozen times — for a total of six and one-half million spray-acres. Twelve million pounds of malathion and a million gallons of sauce base went into the bait spray, and 1,667,217 pounds of dieldrin were used in the bait treatment. A maximum of 800 personnel was involved in the 1956 struggle, as compared to the 6,000 of the 1929 campaign — labor costs of course having risen steeply since the earlier campaign. At the peak of the campaign, some 54,000 detection traps were in use all over Florida, and additional trapping was done in other southern states and Cuba in areas where preferred host fruits grow. About 12,000 fly specimens were caught, and none of these came from states outside Florida. The Florida Legislature has voted funds for continued lure trapping, using combined lures for several fruit fly species in addition to the medfly. In June, 1958, 32,000 traps were still in use throughout Florida.

Harmful Effects of the Campaign

It seems reasonably clear that the two medfly campaigns were completed with little serious loss of wildlife or damage to non-infested crops, domestic animals and human property. The 1956 program received good publicity in the press and on television and radio, and most tropical fish producers were able to cover their ponds, while paint and plastic testing laboratories could spread plastic sheeting over their test plates. Housewives were advised to withhold wash from clotheslines, and automobile owners to cover or be prepared to wash their cars. Some damage was noted on cars with lacquer finishes, but not on those with enamel, and the spotting proved to have been caused by malathion. Some loss of tropical fish was also reported, but not in ponds with deep enough water. Reported losses of birds, mammals and beneficial insects were not confirmed upon investigation. One C-84 twin-engine aircraft crashed at Boca Raton while ferrying materials, killing a crew of five men.

Side benefits from the spray included control or depression of insect pests such as houseflies, mosquitoes and the papaya fruit fly during the period of application.

THE SCREWWORM

Introduction

The screwworm is the maggot (larva) of a large fly (*Callitroga hominivorax,* plus at least one other species occurring outside the area concerned). The maggot lives in the flesh of warm-blooded animals and gets its name from its fancied resemblance to a wood screw. All sorts of mammals are attacked, but from the human standpoint in this country, the damage it inflicts on cattle has been most important. The screwworm has a year-round range in the American tropics and subtropics, from Texas and other border states south to Argentina. Each summer, screwworm flies migrate northward to spread the infestation into the midwestern states, and infestations are known to have been introduced into Illinois, Iowa, New Jersey, South Dakota and other northern states in livestock shipments carrying the pest. Each year up to 1933, winter cold killed the infestation back to the southern parts of the border states and to Mexico, where the winter weather is mild enough to permit permanence of the fly population.

In the summer of 1933, screwworms appeared for the first time in the southeastern United States, probably shipped in infested southwestern livestock, and before they could be controlled they had spread into peninsular Florida. Here they found the climate mild enough to support a year-round population, and thus a permanent infestation became established in the Southeast. Each summer this infestation spread outward from Florida into additional southeastern states, and each winter it died back to Florida and the warmer parts of Georgia and Alabama. During 1935-1937, the affected states in cooperation with the USDA applied the best known animal husbandry practices and tried larvicides and repellents to treat and protect livestock wounds directly. While these expensive measures did help to cut livestock losses, enough larvae survived in neglected livestock and wild animals to keep the infestation alive and dangerous. By 1957, the State of Florida and the Federal Government were ready to support the then new technique of eradication based on male sterilization, and funds were appropriated to begin the campaign against the screw-worm.

Biology and Nature of Damage

The screwworm is an obligatory feeder in the flesh of living mammals. Each female fly lays her eggs in a mass of about 200 on scratches or near exposed wounds on the animals, and the eggs take 12-24 hours to hatch. The larvae then enter the wound and feed extensively on the muscle tissue. As tissue decomposition advances, more and more female flies are attracted to infested wound areas, and the maggot populations at such sites increase correspondingly. The larvae burrow in the tissues for five to seven days, after which they leave the wound and drop to the ground, where they burrow into the soil to pupate. The pupal stage lasts a week or more, depending upon the temperature. The pupa is vulnerable to low temperatures, and freezing soil or prolonged cold kills it. After eclosing from the puparium, the adult flies disperse and seek food. Flies have been found to disperse to distances as great as 35 miles in one week. In the summer, mating begins two days after eclosion, and four to six days later the females have been mated and have laid fertile eggs. The sexes reach adulthood in about equal numbers, and the females mate only a single time, although the males normally mate several times. (Some attention has been given to breeding males that will mate a greater number of times.) Females segregated from males in the laboratory to prevent fecundation oviposit as readily as do mated females. In summer conditions, females live two to four weeks as adults, and may deposit three, four or more egg masses during this span.

Because oviposition is triggered only by the presence of a wound on a suitable host animal, and because of predation of mature larvae by insects, especially by ants, the number of adults produced is rarely high. Uvalde County, Texas, has had the heaviest infestations in the United States, with 100-500 flies produced per square mile per week, but infestations south of the border may be even heavier.

Massive infestations of screwworm can quickly weaken and kill even full-grown cattle, and very small animals often succumb before the flies can complete their larval growth. The pest has caused livestock losses of 20-40 millions of dollars annually, about half of this figure in the Southeast.

Eradication Operations

The story of screwworm eradication in the Southeast begins in 1936 with the work of Melvin and Bushland,[3] who learned how to culture the insect in the laboratory *en masse* on ground meat, blood and water containing a small amount of formaldehyde to retard spoilage. Dr E. F. Knipling, now heading entomological research in the USDA, speculated in conversation in 1938 that the known habits of the females suggested that they might mate only once, which if true meant that laboratory-reared sterile males might be used to control isolated populations such as the one in Florida. The idea was not followed up until after the war, when Knipling directed that the mating habits and physiology of screwworm flies be studied in detail, and that attempts be made to find chemicals capable of rendering the males sterile. In 1950, a general paper was published by H. J. Muller, in which this famed geneticist pointed out that *Drosophila* fruit flies in the laboratory were sterilized by irradiation. A colleague, A. W. Lindquist, passed this paper on to Knipling, who then contacted Muller about the possibility of employing radiation sterilization on screwworms. The reply encouraged Knipling to initiate experiments, and Bushland and Hopkins eventually established that screwworms were readily sterilized by irradiating pupae that had been held at 80° F. for five days. A dose of 2,500 r sterilized males, and 7,500 r prevented egg production altogether. Adult males emerging from irradiated pupae proved able to mate normally with untreated females, but the egg masses resulting were of course infertile. Determination of critical doses proved to be laborious and time-consuming, but cooperation with cytogeneticists soon gave rise to important short-cuts in the process, because damage could be assessed by cytological examination instead of waiting for the full life cycle to carry through in order to get results.

Field tests run on Sanibel Island, two miles off the Florida coast, proved that its screwworm population could be reduced by the release of 100 sterilized males per square mile per week, a figure that surpassed the number of native males. But Sanibel is so close to the mainland that it was easily reinfested, so eradication could not be attempted there.

The conclusive eradication test was finally performed on the Dutch island of Curaçao in the south Caribbean Sea. Screwworms were reared at Orlando, Florida, and irradiated in a cobalt-60 source built at Oak Ridge. At first, flies were released by air at a rate of 100 males per square mile per week, but this proved only fractionally effective because the swarming, unattended goats and sheep of Curaçao harbored a much larger screwworm population than had been encountered in Florida. The release rate was accordingly increased from 100-400 males per square mile per week, and the first saturation of the island with sterilized flies caused substantially more than half of the egg masses laid on test animals to be sterile. After a month of continued releases, when another generation of adults emerged, the native flies were so reduced in numbers that the percentage of sterile matings increased greatly. The emergence of the second generation of wild flies saw the proportions so altered that practically all matings were sterile ones. By generation III, only two egg masses were found in goat pens on the island, and both of these were sterile. No more screwworm eggs were found during the additional two months that flies were released on Curaçao, and release was terminated in January, 1955, less than six months after the first flies were let go.

The Curaçao experiment, heartening as it was, also showed the need for improved procedures for mass production of sterilized males. At a rate of 400 males per square mile, the 50,000 square miles of the overwintering area in Florida was estimated to require 20 million males weekly. The females produced equal the males in numbers and are not easily separated from them in practice, so these doubled the necessary weekly rate of release to 40 million flies. An additional ten million flies had to be reared to make up for mortality of pupae and to provide for breeding stocks. This came to a weekly grand total of 50 million flies, in contrast to the 170,000 larvae raised each week for the Curaçao test.

To meet this demand, experts on insect rearing, irradiation methods and mass production engineering cooperated to transform a large airplane hangar near Sebring, Florida, into a wonderfully efficient plant capable of producing more than the needed number of sterile screwworm flies each week. This plant employed fully modern production line techniques, with the larvae being carried through their feeding life and thence to the pupal stage and the irradiation chamber on a continually moving line of stacked trays suspended from a monorail. Full safeguards were provided against possible escape of unsterilized flies, and elaborate precautions set up to protect the employees from radiation and from the odor of the meat-blood larval food.

Designed, built and equipped on a "crash" basis in just nine months, and at a cost of under a million dollars, the plant moved into full-scale production in July, 1958. By early spring of 1959, it was producing for release at the phenomenal rate of 50-60 million flies per week. The flies were placed in special cardboard cartons that could be opened as dropped from the plane. About 20 light planes were used at the peak of operations, each flying five to six hours a day over prearranged flight patterns based on a few strategic release centers spaced over Florida. Three long trap lines covering the state from north to south provided information on the effectiveness of the operation, and a field force of about 50 livestock inspectors worked on quarantine patrol duty. Stringent quarantine regulations were set up to prevent infested livestock from entering the Southeast from across the Mississippi.

The program had a swift and dramatic effect on the Florida screwworm population. By the middle of March, 1959, all attempts to find egg masses or active screwworm infestations in Florida proved negative. On June 13 of that year the USDA and the Florida Livestock Board could announce, "Southeast free of screwworms for 16th consecutive week." This record was marred in the following week by the discovery of a single case of screwworm infestation in Highlands County, Florida. The releases continued at a rate of about 42 million flies a week, blanketing the area from southern Alabama and Georgia south to Key West. After some weeks during which no signs of a wild fly population were found, the rate of releases was dropped to 30 million flies per week and lower, and finally, on November 14, 1959, fly releases were terminated. The total eradication of the southeastern screwworm population had been achieved.

In the months since the release ended, an infested dog has been found in Florida — evidently brought in from the outside — and during the spring and summer of 1961, infestations have appeared at points along the Gulf Coast from the west, apparently originating from infested livestock shipped from the Southwest. It seems that these new threats to the Southeast can be handled with the available weapons, and the long-range problem now is centered on rolling the screwworm menace back across a defensible line in southern Mexico or Central America, and holding it there by quarantine and possibly by a constantly maintained belt of sterile flies.

COMPARISONS OF THE FOUR PROGRAMS

In comparing operations against the four pests we have just considered, it is well to recall once again that each insect is a separate and distinct problem in control. Some insects have characteristics that lend themselves to simple control methods, while others are just naturally tougher, faster-spreading or faster-breeding, and defy all control methods that have been tried. However, it is also evident that the four programs do differ considerably among themselves in basic ways, especially in the resourcefulness and insight of their planning and operating personnel, in the kind and amount of information upon which control operations are based, and in the adaptability of the operating plans to conditions as they are met while the campaign proceeds. The first factor — personnel — is of course very difficult for one outside of the agencies involved to evaluate, and in any case, judgements are bound to be influenced by hindsight according to the success of the particular program concerned.

The second factor for analysis is the nature and quantity of the information on which each program proceeded. Ideally, of course, a control campaign is based on a full knowledge of the target pest, its life history, ecology, physiology and behavior; on a basic understanding of the efficacy of various methods that might be used against the target; and on a reasonable assurance that these methods do not have seriously harmful effects on valuable plants, animals, microorganisms, inanimate human property, or on man himself. Such knowledge, of which we can never get enough, is provided by previous investigations, by pilot trials, and by continuing evaluation of operational results. These activities, collectively known as research, are the counterparts of intelligence-gathering in a military campaign. The public as well as the technicians involved have come to take research for granted in insect control programs, just as they confidently assume that the proper tests of safety have been applied when a new antibiotic or vaccine is issued by medical authorities.

If we look at the details of the four projects as they have been dealt with in recent years, the differences among them in research effort are very striking. The research behind the screwworm program has been extensive, imaginative and persistent, and obviously it has paid off handsomely. The second medfly campaign, unlike the desperate, scorched-earth first one, was carried out with an efficiency grounded on solid long-term research into the bionomics of fruit flies in general, particularly that conducted by L. F. Steiner and his colleagues in their Hawaiian installation. Here again, it is clear that previous research was crucial in a successful eradication campaign.

The gypsy moth campaign has the longest history, and also the oldest research program, of any of the four efforts considered here. In the years before mass air-spraying, many kinds of measures were tried against the moth, including the introduction of natural enemies already mentioned, as well as cultural methods (such as tree banding and egg mass destruction) and poisons sprayed from the ground. Also built up during the years was a store of knowledge concerning the life history, foodplants, enemies and distribution of the moth, and particularly a fund of information on the effect of the female attractant on males. All this has proven very useful in developing control methods. Nevertheless, the recent work of Campbell (some results of which are outlined above) indicates that there was and is much more of importance to be learned about the behavior of gypsy moth populations than has been generally appreciated. The preparation of gyplure and other attractants in the last few years had doubtless been made easier by technical developments in natural-product chemistry, but perhaps even without these developments more could have been done in the past with attractant research had more time and money been spent on it. To sum up gypsy moth research, one might say that it began rather well and then tended to get into a rut, from which it has been pulled only during the last few years. The present research program is expanding and striking out in new directions, and the outlook now seems rather good for the eventual control of the moth.

As we have already seen, the fire-ant mass spraying program began full blast in the fall of 1957. Considering the very high potency of the poisons used and the great areas over which they were to be sprayed, the research background of the fire-ant program was so sketchy as to be virtually non-existent. USDA investigations ran from 1948 to 1953, and consisted mainly of survey scouting for new infestations plus routine life history, ecological and insecticide-testing work. As already emphasized,[22] no research was done by the USDA from 1953 until *after* the mass spraying had gotten well under way. The Gulfport Methods Improvement Laboratory was not opened until 1958. Nevertheless, in their letters and releases,[23] USDA officials spoke of "expanding" the "continuing research effort," thus giving the impression that an unbroken chain of research studies stretched back from the start of the spray program. The USDA releases emphasize the liaison with the U. S. Fish and Wildlife Service "from the outset," and even seem to imply concurrence of the Service in the mass spray program.[24] As we have already seen from Dr. Leffler's letter,[19] this concurrence could not possibly have been granted at that time. The first meeting of USDA and Fish and Wildlife officers on the fire-ant program took place, according to the USDA, in Washington on December 12, 1957, about a month after the spraying had started. The delay is important in view of the time needed by wildlife researchers to set up and carry out a complicated wildlife survey in an area about to be treated. In fact, the Fish and Wildlife Service seems to have been presented with a *fait accompli* upon which to make its studies.

What about outside research? In the years between 1948 and 1957, Dr. E. O. Wilson at Harvard had continued his work on fire-ant variation, distribution and social behavior, and had discovered the existence of a trail-forming chemical laid down by foraging worker ants. Research on this substance was continued by M. S. Blum and co-workers at Louisiana State University, and is still going on. The active group at Auburn in Alabama studied fire-ant crop damage (which had unaccountably dwindled practically to nothing by 1957) and worked on promising bait formulations. The findings of these groups swerved the spray program not at all. The Gulfport Laboratory is now working on baits and other angles of attack, but insofar as their results have affected the operations to date, emphasis still seems to fall on mass spray methods. No recent specific, detailed study of the damage caused by the ant seems to have been reported, despite the claims of competent state entomologists that crop damage is now negligible. We are left, then, with no concrete information to counter the claims of wildlife experts and state entomologists that the ant is not a major pest deserving of the effort and funds expended upon it. For research effort, the fire-ant program must take low marks.

The last factor to be compared among the programs is their adaptability to conditions met as operations proceed. This is so closely related to the research facet of the respective program that we are not surprised to find the flexibility of operations more or less closely paralleling the quality and amount of research. The screwworm and medfly programs made major adjustments smoothly and without delay as the information available indicated they should.

The gypsy moth campaign has varied; sometimes the operational response to changing conditions was rapid and efficient, while at other times it lagged. Curiosity about the obviously great fluctuations in abundance of the moth, and especially about the great peak following the first extensive air spraying, are not reflected in the impassively literal Annual Reports on gypsy moth control work. Even the overstepping of the Berkshire-Green Mountain barrier seems never to have raised much doubt on the part of the government control officials that the mass spray program in progress would eventually bring about the eradication of the insect in North America, at least to judge from the reports. But events have caught up with the program. The milk residue problem in New York State first halted the program in much of this key "frontier area," and later forced a switch to the less effective sevin for most districts. Finally, a new Methods Improvement Laboratory is opening this year at Otis Air Force Base in Massachusetts, and one way or another we may hope to see some more sophisticated control measures tried against the gypsy moth.

After five stormy years of air spraying, the fire-ant control program goes on pretty much as before, but with greatly reduced dosage in many areas. The reduction seems to have been forced in part by serious wildlife kills and perhaps some destruction of livestock and poultry, as well as by the threat of residues. Where the new double quarter-pound treatment is being applied, damage to warm-blooded animals is apparently not serious. It is, of course, effective against the ants for a much shorter time, and it is doubtful whether its residual effect is up to the task of preventing reinfestation of treated areas. Recently, "mopping-up" activities have been required after treatment in a number of places.

There is a question, already decided in the negative by some of the infested states, whether the eradication campaign should continue in its present form. Not without some logic, wildlife experts have called the fire-ant program, "scalping to cure dandruff." But this campaign has so much momentum, fueled annually with 2.4 million dollars in Federal appropriations, that even the defection of such key participant states as Alabama and Florida has failed to halt it. As the possibility of eradicating the fire ant by the present mass spray techniques recedes into future decades, it will be interesting to see how many more years Congress will vote to keep the present control machinery rolling.

CONCLUSIONS AND RECOMMENDATIONS

The case histories we have reviewed illustrate, I think, the point that mass air spraying of non-selective insecticides can be disappointing as control agents and are in some cases dangerous to the living human environment as well, perhaps, as to man himself. These dangers are usually discussed as "side effects," a term which in itself reflects the special viewpoint of many of the control men on the job. These are "practical" people, absorbed in managing large teams with complex apparatus, and often caught up in the direct urgency of "crash programs." Their efforts are directed at a clear and simple goal — the eradication or control of a particular insect. In the heat of such campaigns, complaints arising from damage to humanly-valued resources are likely to appear as mere incidental annoyances to the control men, and the damage itself is minimized and shrugged off. But the side effects of the control men may in reality amount to catastrophes from other viewpoints, as in the case of the fire-ant campaign. When the cost of a campaign in dollars plus the losses in wildlife, stock or other resources destroyed begins to balance or exceed the benefits to be gained by eradication of the pest, then it is time to give thought to cutting off or drastically modifying the program. In such a case, side effects become main effects, and we should never forget it. The dangers involved in the mass use of pesticides has recently been dramatically recognized in Great Britain,[15] where a Parliamentary Investigation Committee of 43 Members has accused the Ministry of Agriculture of negligence in insecticide research and has recommended that pesticide use be intensively investigated and rigidly controlled, and has called for the "immediate prohibition" of heptachlor, dieldrin and aldrin.

Our case histories illustrate another point: alternative control measures are increasingly available, and we should expect their development to be accelerated. The medfly and screwworm campaigns are shining examples of the results of real thinking and hard work, but most of all they point up the value of new approaches and a sound knowledge of the pest to be dealt with — in other words, they bear the stamp of thorough research.

The issue is clearcut: in the face of a new and spreading insect menace, do we rush out the planes and the poison, or do we first find out what we ought to do and how it should be done, on the basis of adequate information?

The problem of urgency is sure to be raised in answering this question; otherwise, there could be only one answer. In the light of past insect invasions, however, urgency has rarely been so great as to preclude some kind of research assessment of the problem before mass control could begin. Furthermore, research can be called upon to provide a sound body of general background information and principles before the emergency occurs. Our insect control programs often lack this kind of a background, as the makeshift fire-ant campaign illustrates, but when they do have it, as in the case of the medfly, the success of control efforts may be rapid and brilliant.

But in the USDA, entomological research is often hampered at the basic level. Even in such fundamental fields as insect taxonomy and morphology, USDA specialists are for the most part overworked and overcrowded. Daily the cartons of insects submitted for identification pile up on each man's desk, and most of these highly qualifield researchers must work on their own time to get any basic investigations completed. The same is often true of extension entomologists at the state level. Permanent workers in the new and vital disciplines of population dynamics and insect behavior have scarcely begun to be hired by the Federal Government or the states for work in their own fields; yet, as our case histories demonstrate, these fields will surely be pivotal in future control developments. Bright spots in the entomological research picture are the grants from other governmental agencies for the support of basic research, mostly in the universities. But such grants are no substitute for an adequate research establishment within the USDA itself.

From all of these considerations, I think the recommendations must be clear. They are as follows:

1. Every mass control campaign should have an adequate research program functioning as far ahead as possible before control operations get under way. The control work should be guided by the research findings, and not the reverse, and every campaign should be reevaluated frequently to see if a need for it continues.

2. The USDA quickly should be granted funds to expand all permanent research facilities related to pest control. Special attention needs to be given to basic fields such as systematics, physiology, behavior, ecology and genetics. The study of the natural-product chemistry of insects should be stepped up.

3. Mass broadcasting of non-selective poisons, especially spraying and dusting from the air, should be deemphasized and the development of other measures, especially selective lures and sterilization techniques, correspondingly augmented. Over lands other than intensively cultivated agricultural blocks, mass insecticides should be used with the greatest caution and only in real emergencies after other measures have failed. Non-selective insecticides in general should be considered only as stopgap remedies, pending the development of better means of control for all types of land.

4. There should be established a strong permanent inter-agency office to coordinate policies and activities related to pesticidal operations as they affect the biotic environment and human health. This office should have ample funds to allot to the proper agencies for research on specific problems. It would be made up of representatives from the USDA Agricultural Research Service, the Fish and Wildlife Service of the Department of the Interior, and the Food and Drug Administration of the Department of Health, Education and Welfare.

ACKNOWLEDGEMENTS

I am grateful to the many individuals and organizations who made this essay possible, although I cannot mention them all by name here. Particularly helpful were the information and criticisms offered by officers of the Plant Pest Control Division, USDA, and by the following members of my own department at Cornell: Professors H. H. Schwardt, R. A. Morse, A. A. Muka, T. Eisner and G. G. Gyrisco. I also owe thanks to many of the authors listed in the References section below for reprints of their papers and for other material I received from them. It should be understood that those who helped do not necessarily endorse the views here expressed.

Work on this report was initiated by and carried out with the cooperation of The Conservation Foundation, of New York City. I gratefully acknowledge the aid given me by the Foundation's staff.

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Appendix A

[Data furnished by Plant Pest Control Division, Agricultural Research Service, August 25, 1961.]

SUMMARY OF ACREAGE SPRAYED FOR GYPSY MOTH CONTROL, SUPRESSION AND ERADICATION

(All DDT Except As Noted)

	Application By Aircraft (Acres)	Application By Ground Equipment (Acres)	Totals (Acres)
1945	5,103	1,092	6,195
1946	62,201	19,427	81,628
1947	106,677	56,932	163,609
1948	212,260	53,650	265,910
1949	390,576	34,239	424,815
1950	582,895	17,205	600,100
1951	177,713	2,499	180,212
1952	202,109	15,032	217,141
1953	179,451	6,970	186,421
1954	1,371,199	29,817	1,401,016
1955	1,083,169	25,129	1,108,298
1956	926,073	15,391	941,464
1957	3,395,248	27,695	3,422,943
1958	516,150	18,426	534,576
1959	115,078[1]	35,343	150,421
1960	65,538[2]	33,369	98,907
1961	141,270[3]	19,583[4]	160,853
Totals	9,532,710	411,799	9,944,509

		By Aircraft		By Ground Equipment
1959[1]	DDT	29,518 acres		All DDT
	Sevin	85,560 "		
		115,078 acres		
1960[2]	DDT	54,103 acres		All DDT
	Sevin	11,435 "		
		65,538 acres		
1961[3]	DDT	104,770 acres	[4]DDT	19,342 acres
	Sevin	30,000 "	Sevin	241 "
	Methoxychlor	6,500 "		19,583 acres
		141,270 acres		

Summary of Gypsy Moth Defoliation

Calendar Years 1924 to 1960

Year	*Acres*	*Year*	*Acres*
1924	825	1943	34,845
1925	48,560	1944	250,148
1926	80,822	1945	821,487
1927	140,920	1946	622,919
1928	262,514	1947	7,422
1929	551,133	1948	32,467
1930	288,226	1949	78,673
1931	204,721	1950	5,368
1932	286,395	1951	21,314
1933	397,730	1952	293,052
1934	492,361	1953	1,487,077
1935	540,769	1954	491,448
1936	428,622	1955	52,061
1937	608,760	1956	43,158
1938	313,954	1957	6,458
1939	492,640	1958	125
1940	485,636	1959	14,467
1941	468,021	1960	48,722
1942	44,577	1961	data incomplete

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August 16, 1961